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INVENTORY-MONITORING SYSTEM FOR SOUTHERN PINE SEED ORCHARDS

BY

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ABSTRACT

Abstract.--Procedures for an inventory-monitoring system (IMS) are presented for southern pine seed orchards. Total flower counts of selected sample trees are used to estimate the potential cone crop in a seed orchard. Periodic examination of sample branches within each sample tree is used to measure the survival of the initial flower crop and to predict expect-

ed cone and seed yields at cone maturity. IMS is also used to monitor the actual seed production of the individual sample trees. The combined average of all trees or clones is used to evaluate the overall seed production performance of the orchard. When the annual seed production efficiency levels are below acceptable management standards, corrective

procedures should be implemented to increase the yield of seed. With IMS, the feasibility of increased management costs can be evaluated in terms of expected gain in seed production.

Key Words: Seed Production, Insect Control, Loblolly Pine, Tree Improvement, Cone Production.

INTRODUCTION

Genetically improved seeds from southern pine seed orchards are the product of a long-range program of tree selection and progeny testing; a large capital investment in orchard establishment and equipment; and high annual costs of orchard maintenance, protection, and harvesting. Seed orchard yields as well as orchard management could be improved if an adequate Inventory-Monitoring System (IMS) was available. The system can be used to monitor the actual seed production efficiency for each orchard, give an overall seed orchard-to-nursery efficiency

value, forecast annual cone crops, and estimate the number of bushels of cones, seeds, and seedlings that can be expected. Economic feasibility of additional management inputs and costs could then be balanced against the expected gain from the production of additional seeds and seedlings.

Few guidelines exist for this type of sampling and inventorying system. Cone crop life tables to determine when mortality occurred have been used to assess the impact of various mortality factors, and to provide a direct accounting of seed

losses (5). Also, cone analysis as a method of comparing actual seed yields to potential seed yields and expressing the productivity in terms of seed efficiency has been developed (2,3). Godbee *et al.* (6) used a sample tree system in slash pine to evaluate the efficacy of an orchard insect control program. The IMS described in this report is a refinement of the procedures adapted from Godbee, and can be used to predict and evaluate the seed production from seed orchards on a continuing basis.

CONE AND SEED CROP INVENTORY

Selection of Sample Trees

The IMS uses only sample trees to inventory and predict the seed production for each cone crop in a seed orchard. The entire flower crop is counted on each sample tree, so it is important to use as few samples as possible to save time, yet have enough for a reliable prediction. The number and selection of trees depends upon the orchard manager's objectives, available personnel, the equipment needed to count the trees, and the variability within the orchard. The major sources of variation in flower production are annual climatic effects during flower initiation, clonal effects, age of the ramets (within clones), site effects, and cultural practices. There are several bases for selecting sample trees:

Estimating Orchard Productivity

To evaluate overall seed orchard productivity yet use a minimum of sample trees, a completely random sample of trees is selected from the entire orchard population, which gives each individual tree an equal opportunity to be selected. This procedure is normally accomplished by using a random number table. If, for example, the orchard had 50 rows and 40 columns, randomly selected row and column numbers would designate a single randomly selected sample tree. The process can be repeated to select from 1 to 5 percent of the total number of ramets in the orchard. For example, a 2,000-ramet orchard could have from 20 to 100 sample trees. Obviously, the larger number of samples will give the better estimate but orchard managers must weigh inventory costs against the value of information.

Although this sampling procedure gives the most reasonable estimates with the fewest sample trees, it does not give reliable information about individual clones; every clone may not be represented, and few clones have more than one sample ramet. Orchards with many clones are highly variable and require a larger number of sample trees. In contrast, rogued orchards have fewer ramets, so the variation and number of sample trees might also decrease.

Estimating Orchard and Clone Productivity

If the objective is not only to evaluate the orchard productivity but also to measure clonal seed production, then all clones must be included in the sample. The individual sample trees are selected from an inventory list of all ramets within a clone by using random number tables.

For example, if each of 40 clones had 50 ramets each, then random numbers would be used to select 3 to 6 ramets per clone. This procedure, which gives estimates for the overall orchard and clonal seed and cone production, requires a large number of sample trees so it is the most expensive sampling design to implement. In addition, when clones have varying numbers of ramets, the number of sample trees selected should be in proportion to the number of ramets per clone.

Estimating Productivity of Sample Clones

In this sampling procedure, only a portion of the clones is selected from the total. For example, one-third of the clones could be randomly selected, then three to six ramets could be randomly chosen from a list of ramets within each of these clones. With this procedure, a reliable estimate of orchard performance can be derived and the variability of clones evaluated. Fewer sample trees are used than if all clones were sampled, however, seed production data are available for only the clones actually included in the sample.

Estimating Productivity of Stratified Clones

In this procedure, clones are classified on the basis of cone production. For example, in a 40-clone orchard, 10 clones might be classified as good producers; 20, classified as moderate; and 10, as poor. A proportion of the clones is then randomly selected to represent each production class. Because the bulk of the cones will be from the good producers, more sample clones should be selected in the high production class. For National Forest Seed Orchards, we recommend approximately 16 sample clones for a 50-clone orchard. For each orchard, eight clones are randomly selected from the good cone producers, five from the moderate, and three from the poor. For each selected clone, three to six randomly selected ramets serve as sample trees. Weighted average values for clones within each production class are summarized to obtain inventory and monitoring information about selected clones and generalized information for the entire orchard. To use a stratified sampling procedure, some knowledge of the cone production of each clone is required. The production of specific clones may vary in different years, so that after several years their classification may need to be adjusted.

Sampling Older Orchards

In older or more intensively managed orchards, flower production and seed

yields are usually less variable, and fewer sample trees may be required. When the orchard is rogued, sample trees may be removed on the same basis as any other tree. For example, sample trees might be lost when genetic roguing removes all ramets of a clone, or when silvicultural thinning is used to achieve the desired spacing. Sample trees can be replaced from the orchard population after the thinning is completed, if necessary. As flower production increases, the time and difficulty of annual flower counting greatly increases. Young orchards, for example, may have six ramets per clone but as the orchard gets older the manager may want to reduce the sample trees per clone to only three. The sample trees to be eliminated should be determined by evaluating the seed production records. Sample trees that show large annual variability in production or those that do not follow the trend for the clone or orchard are eliminated in favor of the more "reliable predictors" of orchard performance.

Sample Tree Flower Count

Identification of each sample tree is entered in cols. 1-23 of both the Sample Tree Data Sheet (Figure 1) and the Sample Branch Data Sheet (Figure 2).

The number of female flowers (NF) is obtained from total flower counts of sample trees. These counts should be made 1 to 4 weeks after pollen release and entered in cols. 24-27 of the Sample Tree Data Sheet. Counts are usually made from a hydraulic lift truck by systematically scanning each branch or portion of the crown and recording the total flowers observed. All dead and damaged flowers are included in the count. Female flowers are most visible at the time of receptivity and become increasingly difficult as the needles elongate.

Predicted Total Seed Production

Once the total flower crop has been counted for all sample trees, a predicted total number of seeds (PTS) produced from each individual tree included in the sample can be described as follows:

$$PTS = NF \times PCE \times PSP \times PSE$$

where: PTS = predicted total number of filled seeds produced

NF = number of female flowers per sample tree

PCE = predicted cone efficiency for the sample tree

PSP = predicted seed potential for the sample tree

PSE = predicted seed efficiency for the sample tree

From the Sample Tree Data Sheet, NF is obtained from the total flower count entered in cols. 24-27. The PCE from cols. 52-53, PSP from cols. 49-51, and PSE from cols. 54-55 are described below.

Predicted Cone Efficiency

Cone efficiency (CE) is the ratio of healthy mature cones to the original total flower crop. The predicted cone efficiency (PCE) is an expected value for a given year's CE and is a vital part of the predictive model; it is not measured but is the best estimate available based on knowledge of orchard performance. From our experiences with first-generation orchards, CE estimates are as follows: Intensively managed orchards with effective insect control, CE = 0.70 or higher; moderately managed orchards, CE = 0.50-0.70; and poorly managed or natural stands, CE = 0.50 or less. After several years, the estimate for an individual orchard can be based on the average value of cone efficiencies observed in the monitoring of previous years' cone crops.

Cone efficiency usually increases with the age of the orchard; as the pollen becomes more abundant, a higher proportion of the female flowers survive. In addition, as older ramets produce more flowers, the percentage of cone survival normally increases if effective insect control is part of the overall orchard management plan. For example, if only 20 flowers were initiated, a loss of 10 would equal a CE of 0.50. If 100 flowers were initiated, a loss of 10 cones would give a CE of 0.90.

The average CE value for all individual sample trees (ramets) is used to determine the annual cone efficiency of the orchard (or clone). This annual CE value is derived from monitoring the fate of the female flowers on permanently identified sample branches on each sample tree, by the following procedure.

Selection of Sample Branches.--At the time of the annual flower count, eight sample branches^{1/} on each sample tree are selected and permanently tagged with a metal tag (uniquely numbered) and copper wire. Enter the number of each branch on the Sample Branch Data Sheet in cols. 24-27. All flowers from the tag to the tip of the branch are included in the sample count. The branch should also be flagged with short flagging for later recountings.

The selected sample branches should

be "representative" of the flower crop in all crown positions. The branches are systematically distributed throughout the cone-bearing portion of the tree crown but are located so that only one setting of the hydraulic lift truck is required to visit all sample branches. Orientation of branches would normally represent approximately 270° of the crown circumference. Each sample branch should contain at least 1 and up to 20 female flower primordia. The sample branches should normally have a total of 40 to 60 flowers or about 10 to 25 percent of the total flowers on the tree.

Counting Sample Branches.--When the initial flower count is made, all flowers on the sample branches are counted and recorded on the Sample Branch Data Sheets. The total number of flowers including dead flowers are recorded in cols. 28-30. The live flower count is entered in cols. 31-33 as the April total. No attempt is made to record all causes of mortality but space is available to make notes on observed mortality due to frost, insects, etc., in cols. 49-80 of the data sheet.

Periodic Sample Branch Counts.--The sample branches are recounted at periodic intervals to track the survival of the initial flower crop. Set the bucket truck in the same location as for the original count for ease of recounting. Observation dates will include the initial count in April^{2/} followed by a recounting in July and October of Year 1. At each counting only the apparently healthy conelets or cones are recorded in cols. 34-36 and 37-39. As in earlier counts, mortality is not recorded but observations can be noted in cols. 49-80. In the second year of development, recounts of the sample branches are made in April and July and recorded in cols. 40-42 and 43-45. A final count of healthy mature cones is made in October of Year 2 (cols. 46-48) when cones are harvested and sample cones collected for cone analysis. For each observation date, the number of surviving conelets or cones on all eight branches per tree is totaled and entered in corresponding columns (28-48) on the Sample Tree Data Sheet.

Continuing Annual Branch Counts.--As IMS is used in succeeding years, two or more new sample branches are selected each year and a corresponding number of the original branches eliminated on the basis of poor flowering or crown position. Sample branches with more than 20 flowers should be subdivided to avoid the

problem of counting large numbers of flowers. For example, a vigorous branch in the upper crown would probably be too large after 2 years of growth and should be replaced after mature cones are counted. Sample branches with no flowers are discontinued after the conelets become mature cones. A separate set of both Sample Tree and Sample Branch Data Sheets is used for each annual crop. Observations from sample branches at cone maturity are used to monitor the actual cone efficiency (CE) value for each date, where CE = observed number of cones/initial number of flowers. This value can then be used to calculate the PCE for the continuing years of the IMS.

Predicted Seed Potential

The seed potential (SP) is the biological capacity of each individual cone to produce seed (2). As each fertile scale has the capacity to produce two filled seeds, the seed potential is calculated by multiplying the number of fertile scales by two, i.e., $SP = 2 \times \text{No. fertile scales}$.

SP is a morphological trait characteristic of each species and individual clone. Variation within a clone (CV) is usually low (about 10 percent) and the degree of annual variation is usually not very large. For the predictive model, information from previous cone analysis is used; if unavailable, average values for each species (3,7), can be used:

loblolly pine, 143-155; slash pine, 170-181; longleaf pine, 147; shortleaf pine, 87-92; Virginia pine, 88-90.

Actual SP values will be accumulated as monitoring of the orchard continues. When the values appear reasonably constant from year to year, an average value for each sample tree or clone can be used.

Predicted Seed Efficiency

Seed efficiency (SE) is the ratio of filled seeds to the seed potential (2). This value is an excellent indicator of seed production performance because it compares the actual yield to the maximum biological capacity of the cone. To predict seed efficiency, the same procedure is used as to predict cone efficiency. For the first year of inventory, a "best estimate" should be used. Suggested estimates of SE are as follows: for intensively managed seed orchards, with excellent insect control, SE=0.55 or higher; moderately managed orchards, SE=0.35 to 0.55;

^{1/} A sample branch equals an observation unit and normally is not an entire branch but a branch tip containing several flowering locations.

^{2/} Loblolly pine is counted in April. Other species may be earlier (slash) or later (shortleaf).

and natural stands or minimally managed orchards, SE=0.35 or less. For subsequent years, predicted seed efficiency (PSE) is derived from the average of previous years.

As with CE, SE usually increases with age, primarily as a result of more abundant pollen production as the orchard matures. With increased pollen supply, fewer ovules abort from lack of pollen and self-pollination may be reduced so that fewer empty seeds are formed as a result of embryo mortality. Unfortunately, SE cannot be easily measured prior to cone harvest. It is possible to use a cut count of exposed seeds in sliced green cones (1,4,8) but in this report, PSE is not updated before cone harvest.

Actual SE is calculated by randomly sampling three or more cones from each sample tree at cone harvest. Each cone is placed in a separate paper bag with proper identification and air-dried until scale separation begins. Cones are then dried for 24 hours at 40°C. Analysis of sample cones follows the guidelines of Bramlett *et al.* (2). Cone analysis monitors seed yields per cone, seed potential, seed losses, and seed efficiency for each clone. After several years of baseline data are accumulated from cone analysis, we anticipate that the total removal of all scales may be discontinued and that the extractable seeds can be used as a primary estimator of seed efficiency.

Updating the Predicted Cone Efficiency

The prediction of total seed production in the orchard can be updated as the sample branch data are accumulated from each sample branch counting date. From past experience, a proportion of total mortality occurs within certain time periods. For example, in a loblolly pine seed orchard^{3/} near Greensboro, Georgia, flower and cone crops were observed on sample trees at six periodic intervals for 2 years. Flower, conelet, and cone survival decreased during the 2-year observation period as shown in Figure 3. In this orchard, 58 percent of the original flower crop was present as mature healthy cones.

In a generalized life table of cone survival (Figure 4) for a managed southern pine seed orchard, expected mortality can be estimated for each observation period. In this approach, the cumulative expected mortality by date is as follows: for Year 1, April=5 percent, July=15 percent, October=20 percent. For Year 2, April=25 percent, July=30 percent, October=40 percent. Thus, as the cumulative mortality increases with time, cone efficiency progressively decreases to an estimated

60 percent at the time of cone harvest. As described in the counting techniques, causes of mortality are not listed and the life table presents only the number of healthy cones present at a given observation date. An expected life table can be developed for each orchard based on previous observations or best estimates of cone survival patterns. For example, orchards with high coneworm mortality may have heavy losses in late summer of Year 2. Or, frequent frost damage could produce severe losses in April of Year 1.

The generalized life-table curve (Figure 4) is used in the IMS as the expected survival pattern for a given cone and seed crop. A survival curve should be produced for each orchard if adequate data from previous year's observations are available. Deviations from the expected curve can be used to adjust the estimated final cone and seed crop as the crop approaches harvest time. To update the predictive model, a new PCE value is calculated at each observation date. If the CE=PCE then no changes are made in the predicted cone and seed yields.

The updated predicted cone efficiency (PCEu) can be calculated at each observation date by the following formula:

$$PCEu = PCE + CPM - COM$$

where:

PCEu=update of predicted cone efficiency

PCE=predicted cone efficiency

CPM=cumulative predicted mortality to date

COM=cumulative observed mortality to date

For example, if the PCE was 60 percent for a seed orchard, the generalized predicted life table (Figure 4) would show a cumulative predicted mortality (CPM) of 20 percent by October of Year 1. If the cumulative mortality (COM) was greater than 20 percent, then a lower CE for the cone crop would be expected. Thus, for an observed COM of 30 percent by October of Year 1, then

$$PCEu = 0.60 + 0.20 - 0.30 =$$

$$PCEu = 0.50$$

Based on this update, 50 percent survival of cones is the new predicted value rather than the original PCE of 60 percent. Conversely, a lower than predicted mortality could raise the PCE at any given observation date. For each observation date a current value of predicted total seed is calculated.

Predicted Orchard Seed Production

The predicted seed production from the entire seed orchard (OPTS) is the cumulative total of all observed sample trees (or clones). The total count is averaged for all trees and then multiplied by the total number of ramets in the orchard. When clonal values are used, the total flower count used to determine orchard production is the average of all sample ramets within that clone.

$OPTS = (PTS_1 + PTS_2 + \dots + PTS_n) \div n \times NR$
where:

OPTS=predicted total number of seeds from the orchard

PTS_1 =predicted total number of seeds from sample tree 1 (clone 1)

PTS_2 =predicted total number of seeds from sample tree 2 (clone 2)

PTS_n =predicted total number of seeds from sample tree n (clone n)

n=total number of sample trees

NR=total number of ramets (clones) in the orchard.

The OPTS gives the total number of seeds produced in each orchard but does not consider the actual quantity of seeds after extraction. To quantify seed yields on the basis of available seeds after extraction, an extraction efficiency must be predicted.

Estimated Extraction Efficiency

Extraction efficiency measures the percentage of seed removal from each cone in the extraction process. Many commercial extractors have a high extraction efficiency, and laboratory procedures are available (4) to simulate this operation. The degree of cone opening is the most important factor in extraction, and cones that open poorly will have lower seed extraction efficiencies in both laboratory and operational extraction. For the prediction equation, estimated extraction efficiency (EEE) is based on operational extraction to calculate annual seed yield. The actual extraction efficiencies for sample trees or clones are monitored from laboratory analysis of sample clones. Adjustment can be made in the EEE if the operation extraction process is modified. The orchard predicted extracted seed (OPES) is calculated as follows:

$$OPES = OPTS \times EEE$$

where:

OPES=predicted number of extracted seeds from the orchard

^{3/} Cooperative Study No. FS-SE-1117-106 of Southeastern Forest Experiment Station and Georgia Kraft Company. Data on file, SEFES, Macon, Georgia.

FIGURE 1 - SAMPLE BRANCH DATA SHEET

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use as field data collection form.

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FIGURE 2 - SAMPLE BRANCH DATA SHEET

(on other side)

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Figure 2.--Snp

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OPTS=predicted total number of seeds from the orchard

EEE=estimated extraction efficiency from operational extractory or from average EE values of previous cone analyses.

Predicted Bushels and Pounds of Seed

Seed orchard yields are most frequently measured in bushels or pounds of seed for harvesting, extracting, and storage procedures. The predicted number of seeds produced can be converted to bushels or pounds of seeds on the basis of predicted values for each individual sample tree or clone.

$PBU = (NF \times PCE) \div \text{No. cones/bu}$

where:

PBU=predicted number of bushels of cones

NF=number of female flowers for sample tree (clone)

PCE=predicted cone efficiency for sample tree (clone)

No. cones/bu=average number of cones per bushel for sample tree (clone) (cols. 75-77, Figure 1).

The orchard predicted number of bushels of cones (OPBU) would equal:

$OPBU = ((PBU_1 + PBU_2 + \dots + PBU_n) \div n) \times NR$

where:

PBU_1 =predicted bushels of cones from sample tree 1 (clone 1)

PBU_2 =predicted bushels of cones from tree 2 (clone 2)

PBU_n =predicted bushels of cones from sample tree n

n=total number of sample trees

NR=total number of ramets (clones) in the orchard.

The predicted pounds of extracted seed (PLB) could be calculated for each sample tree from the predicted total number of seeds as follows:

$PLB = (PTS \times EEE) \div \text{No. seed/lb}$

where:

PLB=predicted pounds of seed

PTS=predicted total seed

EEE=estimated extraction efficiency
no. seed/lb=average number of seeds per pound for each sample tree (clone) (cols. 78-80, Figure 1).

The total predicted pounds of seed from the orchard (OPLB) is more useful than for individual trees. This value could be obtained by cumulating all individual values of $PLB/n \times NR$ or by dividing the OPES by the average seed per pound for the orchard.

Predicted Number of Seedlings

To provide planting stock for regeneration, the orchard seed must be capable of germination. The predicted number of seedlings (PVS) in a potential cone crop is estimated by the expected number of viable seeds in a given lot. This value is derived by multiplying the total number of extracted filled seed by the expected percent germination. The predicted germination efficiency (PGE) is based upon the average of past records. If these data are not available for individual sample trees or clones, then averages for the seed orchard location may be used. The reliability of the PGE can be obtained by comparing it to actual germination data derived from monitoring seed collections from each sample tree or clone.^{4/}

The predicted number of seedlings (PVS) per sample tree (clone) would equal:

$PVS = PES \times PGE$

where:

PVS = predicted number of seedlings
PES = predicted number of extracted seeds

PGE = predicted germination efficiency

The orchard predicted number of seedlings (OPVS) would equal:

$OPVS = ((PVS_1 + PVS_2 + \dots + PVS_n) \div n) \times NR$

where:

OPVS = orchard predicted number of seedlings

PVS_1 = predicted seedlings from sample tree 1 (clone 1)

PVS_2 = predicted seedling from sample tree 2 (clone 2)

PVS_n = predicted seedlings from sample tree n

n = number of sample trees

NR = total number of ramets (clones) in the orchard.

MONITORING ANNUAL SEED ORCHARD PERFORMANCE

The inventory capability of the system provides a continuing record of cone and seed development and predicts yield values for cones and seed crops up to 18 months before cone harvest. In addition, the actual values observed for seed performance can be used to monitor the annual efficiency of seed production from each orchard. This value is derived as a product of four separate efficiency values: cone efficiency, seed efficiency, extraction efficiency, and germination efficiency. Thus, the product of these

values gives the overall seed orchard-to-nursery efficiency (SO-NE) and equals:

$SO-NE = CE \times SE \times EE \times GE$

where:

CE = cone efficiency

SE = seed efficiency

EE = extraction efficiency

GE = germination efficiency.

Cone Efficiency

The annual CE is derived from each sample tree at the time of cone maturity. For each tree the final sample branch count in October gives the survival from flower to mature cone. Cones can be classified as dead or damaged but only healthy cones or cones with minor damage that would be sent to an extractor should be included in the final cone count.

The total of all sample branch cone counts is then entered in cols. 46-48 of the Sample Tree Data Sheet. CE is then the ratio of mature healthy cones to the original flower crop. These data are entered in cols. 63-65. The measured CE values for each tree are then used for the next year's PCE as described in a previous section.

Seed Efficiency, Extraction Efficiency, and Germination Efficiency

The observed SE is measured from a cone analysis of sample cones collected from the sample trees. As in the selection of sample trees, the procedure to select cones for analysis depends on the orchard manager's objectives and the sampling design. The total number of sample cones per orchard may vary from a minimum of 60 up to several hundred. Typically, 3 to 5 cones from each sample tree should be used for cone analysis and a minimum of 10 cones per clone is usually adequate for a given year. The standard collection procedure is to remove all mature cones from the tree and then "blindly" pick the sample cones from a burlap bag or other container of cones. Once the cones are collected in the orchard, each cone is placed in an individual paper bag with tree and location identification. Cones are allowed to air-dry until scale separation begins and then cone analysis (2) is completed on each cone.

From the cone analysis, the observed values of SE for each cone are averaged and entered in cols. 66-68 of the Sample Tree Data Sheet. In addition to SE, other parameters are measured for each sample cone and averaged for each sample tree. These include, SP (cols. 60-62), EE

^{4/} Laboratory germination may be considerably higher than field germination. PVS in this procedure only relates to laboratory germination. Further reduction in PVS would be necessary if nursery germination was substantially lower than laboratory tests.

UTILITY OF INVENTORY-MONITORING SYSTEM

The product of the four efficiency values gives the SO-NE for an individual sample tree. These efficiency values measure the performance of seed production for each tree (or clone) and when combined give an overall evaluation of seed production of the orchard. For example, a SO-NE value of 0.45 (Figure 5) may represent an intensively managed seed orchard (3). Yet, values substantially below 0.45 are frequently observed in southern pine seed orchards. With the use of the IMS, orchard managers can evaluate their current level of production and either maintain production at current levels or

identify the factors reducing yields.

Insects, diseases, and climatic changes are major limiting factors in attaining a reproductive efficiency in southern pine orchards. Some causes of mortality are easily identifiable and may even result in spectacular losses. Other causes are rarely abundant enough to be considered serious as a single item, yet in combination with other losses cause a consistent loss from year to year. Although IMS does not identify specific causes of seed losses or predict the unusual high losses, the system provides information on annual cone and seed production and gives an estimate of total losses for each cone and seed crop.

Few guidelines currently exist for evaluation of management strategies and the setting of management goals for seed

orchard production. The IMS described provides information on annual production levels and possible areas of concern. Efficiency levels below acceptable management standards indicate that corrective procedures could result in more seed and seedlings. Orchard managers with excessive losses can further examine the causes of seed and cone mortality and evaluate their current pest protection management plan. Thus, when the seed production is accurately quantified, the difference between the orchard potential and the actual pounds of seed produced can be used to estimate the amount and dollar value of seeds that are lost. The feasibility of increased management costs, such as increased insect protection, can then be evaluated in terms of the expected gain in seed protection.

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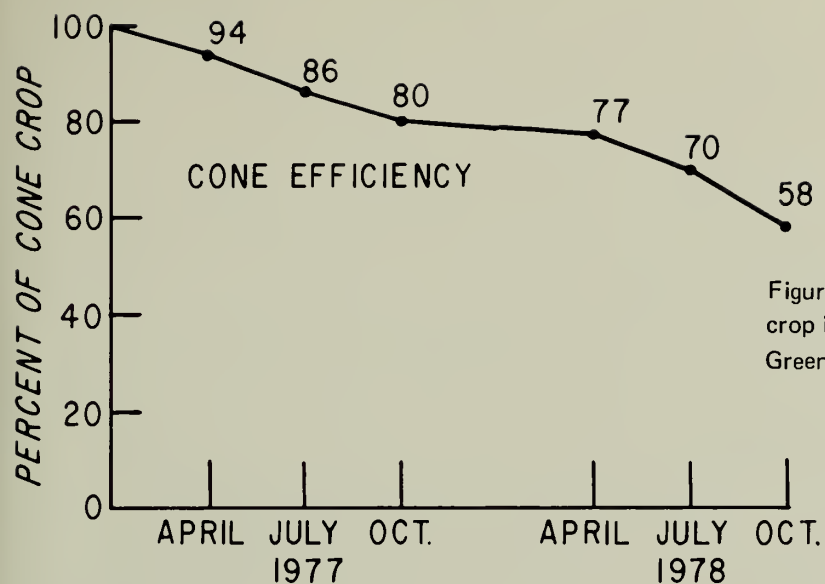


Figure 3.--Cone efficiency (survival) of the 1977-78 cone crop in Georgia Kraft's Loblolly Pine Seed Orchard, Greensboro, Georgia.

Figure 4.--Generalized cone efficiency and periodic mortality for managed southern pine seed orchards over a 2-year period.

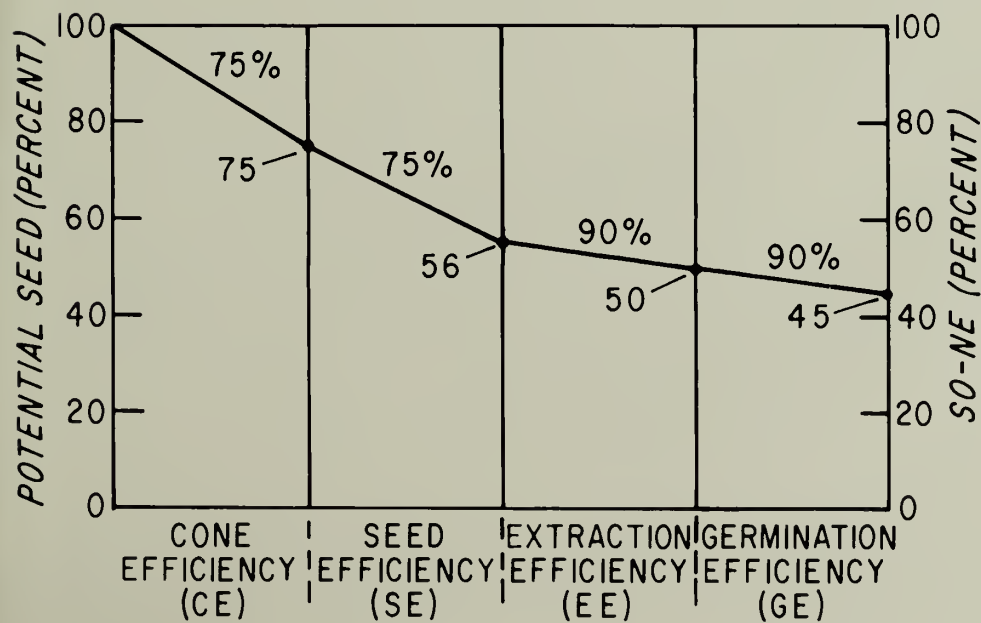
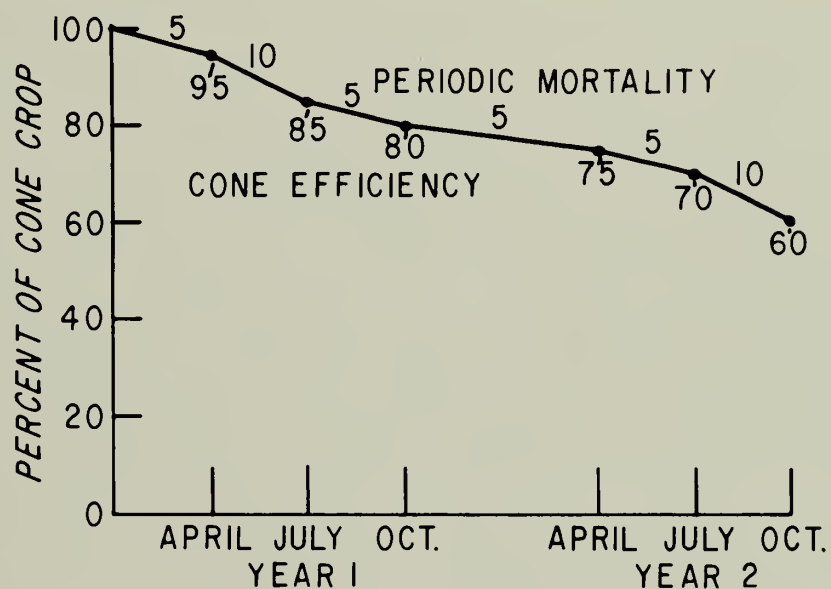


Figure 5.--Seed orchard-to-nursery efficiency (SO-NE) of a given potential seed crop to produce viable seed. $SO-NE = CE \times SE \times EE \times GE$.

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